Laser-based vernier calliper gauge

enables contact-less measurements

The calliper gauge described in this article is not an optoelectronic* device, although it is based on the marriage of a laser (optics) and electronics. It is an excellent example of the way optics and electronics can be made to work together. Like its mechanical counterpart, it is very accurate, gives fast results and need not touch the object to be measured.

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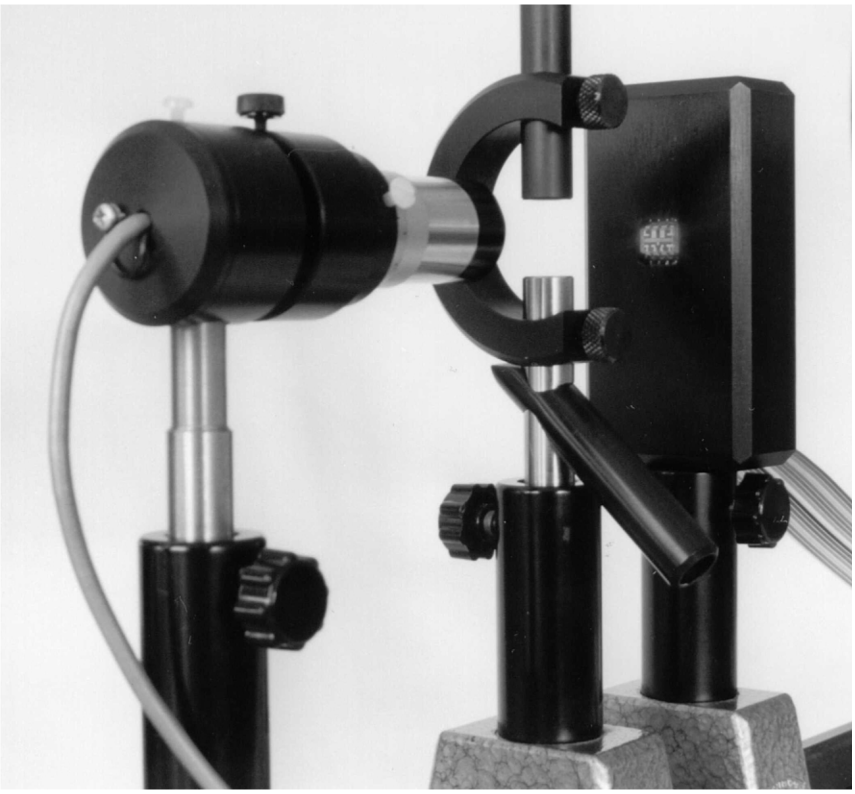

THE PRINCIPLE

Mechanical vernier calliper gauges have two parallel surfaces between which the object to be measured is placed: it does not matter how it is so placed—see **Figure 1**. In the optical equivalent the object is scanned by a parallel beam of light. Such a beam may be obtained by passing light from a point source through a collimator. An excellent point source for the present purpose is a laser diode.

A collimator is a device or system that produces a beam of (near) parallel light. For use with a laser diode, it needs a very short focal length (of the order of millimetres) to convert the strongly divergent beam from a laser diode into a parallel beam. Since with such a short focal length serious image errors may occur, the collimator is usually a combination of lenses instead of a single lens.

In the vernier calliper gauge, the eyepiece of a microscope was used, but the tube of a small pair of binoculars will also do. The reader may note that multi-lens collimators are commercially available.

The object to be measured is placed in the parallel laser beam so that it throws a shadow on to an optical sensor, a diode array or a charge-coupled device—CCD. Owing to the parallelism of the beam, the dimensions of the shadow are exactly the same size as those of the object—see Figure 1.

*Optoelectronics is the study and application of electronic devices that emit light (lasers, light-emitting diodes), amplify light (optical amplifiers), detect light (photodiodes, phototransistors), and control light (Kerr cells).

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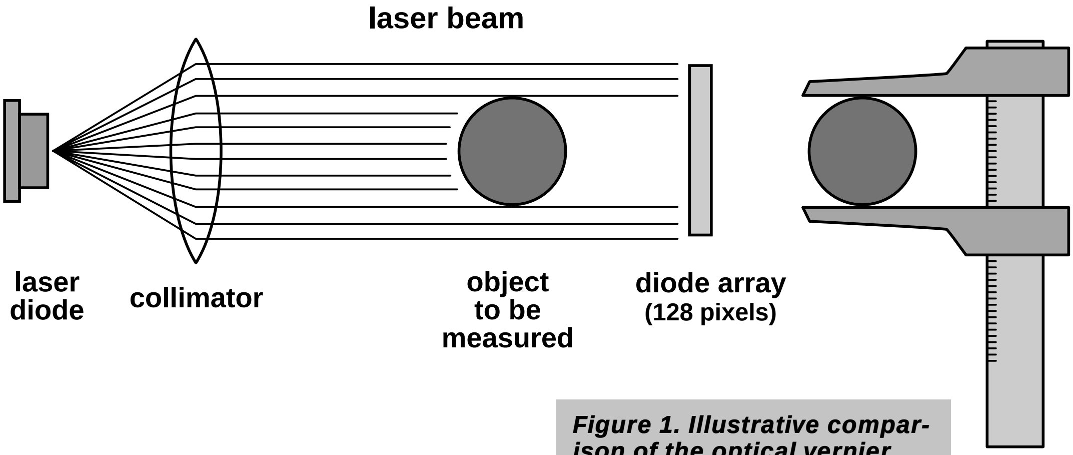

Figure 1. Illustrative comparison of the optical vernier calliper gauge and its mechanical counterpart.

LINEAR SENSOR ARRAY TSL401

Charge-coupled devices need several supply voltages and complex control signals, while their output signal requires additional analogue processing. In contrast, the Type TSL401 linear sensor array from Texas Instruments' provides a readily usable output signal, and needs only a single 5 V supply line and two logic signals. The functional block diagram of the sensor is shown in **Figure 2**.

The TSL401 consists of a 128×1 array of photodiodes and associated charge amplifier circuitry. The pixels measure 63.5 µm high by 50 µm wide with 63.5 µm centre-to-centre spacing and 13.5 µm spacing between the pixels.

Light energy striking a pixel generates a photocurrent that is then integrated. The amount of charge accumulated at each pixel is directly proportional to the light intensity on that pixel and the integration time. The integration time is the interval between two consecutive output periods.

A 128-bit shift register controls the output period of the device. An output period is initiated by the application of a high logic level to S_1 for one leading (positive-going) clock edge. The logic 1 is clocked through a 128-bit shift register, in which one bit is associated with each pixel. When a given bit is high, the associated pixel signal is coupled to the analogue output (AO) through an output amplifier. When the bit goes low, the integrator is reset.

The output amplifier is a source follower that needs an external pulldown resistor. The source-follower configuration permits an analogue wired-OR hookup of multiple devices. When the device is not in the output phase, the output is in a high-impedance state. The output is nominally 0 V for no light input and 2 V for a nominal light intensity.

The TSL401 is intended for use in a wide variety of applications, including mark and code reading, optical character recognition (OCR) and contact imaging, edge detection and positioning, and optical linear and rotary encoding.

More detailed information on the sensor array is available on the Internet: **http://www.ti.com/sc/docs/folders/analog/tsl401.html**

CPLD INSTEAD OF MICROCONTROLLER

The sensor array may be controlled by a CMOS Programmable Logic Device (CPLD) instead of a microcontroller. A good choice for this purpose is the Type ispLSI1016 from Lattice (described in *EE*, November, 1994).

This device contains 64 macrocells, which makes it ideally suitable for simultaneously generating control signals for the array and providing an interface for connecting it to a computer. See **Figure 3**.

A dedicated programming unit is not needed, since the logic may be input directly into the CPLD via the parallel port of the computer.

Since the download cable also provides a link between the CPLD and the computer, the measurands may be sent directly to the computer. Before this can be done, however, the cable as well as the isplLSI1016 board need a few small modifications. Information on these is available on Lattice's Homepage: **www.latticesemi.com**

CONTROL LOGIC AND INTERFACE

The overall logic is in synchronous format: all registers are clocked centrally by a 16 MHz system clock. Asynchronous signals are integrated into the oscillator signal by bistables.

The 2 MHz pixel clock for the sensor array is derived from the system clock, so that a pixel clock period consists of eight phases. This means that the signals needed for processing the pixels may be synchronized with an accuracy of an eighth of the pixel clock period.

The logic signals in the isplLSI1016 are applied to modules contained in the CPLD as shown in **Figure 4**.

SYNCHRO

Control signals MODE and SCLK, with which the computer starts the serial reading of the data, are not in synchrony with the system clock. They are, therefore, synchro-

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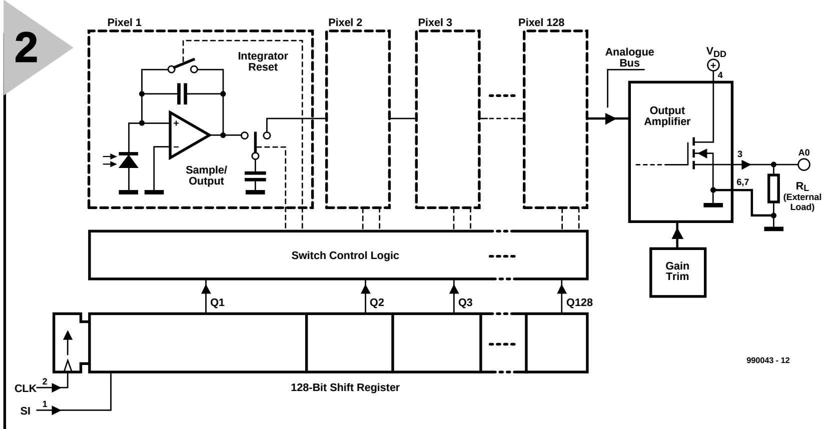

Figure 2. Functional block diagram of the Type TSL401 linear sensor array.

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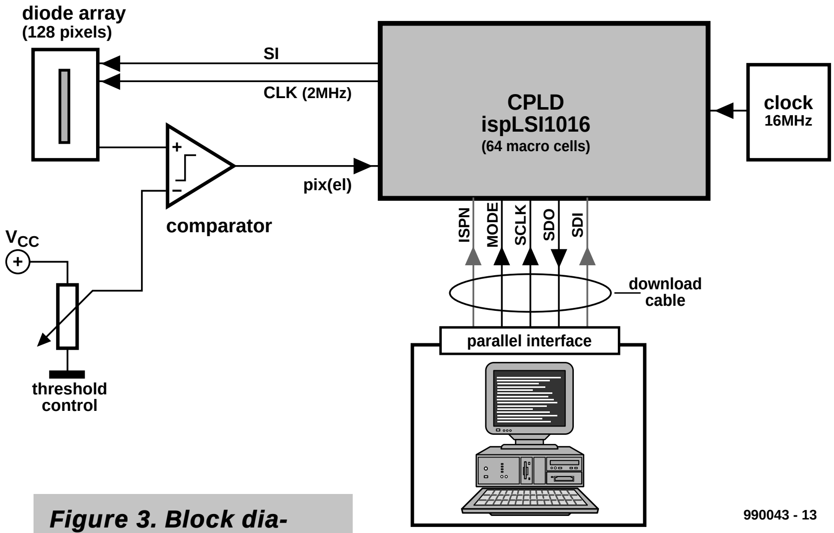

Figure 3. Block diagram of the electronic part of the vernier calliper gauge.

Figure 4. The requisite logic functions contained in the ispLSI1016 for sampling the measurand.

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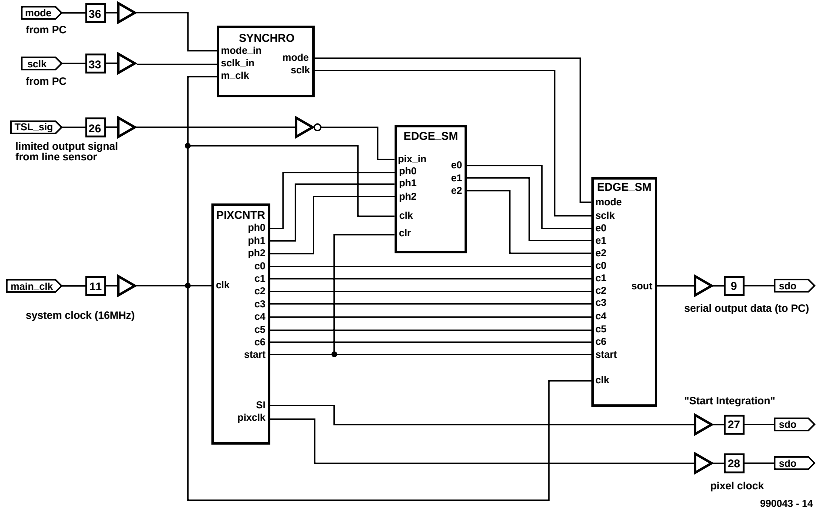
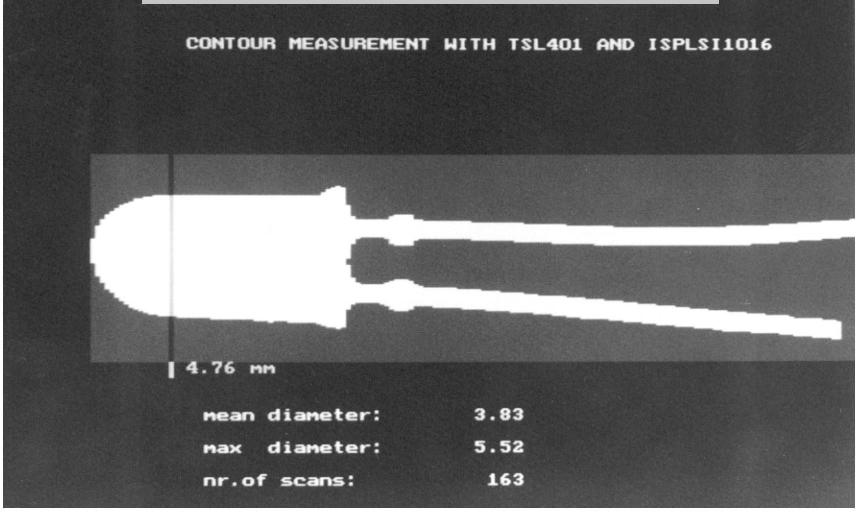


Figure 5. Screendump of the contour measurement of a light-emitting diode (LED)



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CONTOUR MEASUREMENT WITH TSL401 AND ISPLSI1016

4.76 mm

mean diameter:        3.83
max  diameter:        5.52
nr.of scans:           163
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nized with it before being applied to the remainder of the module.

PIXCNTR

The PIXCNTR module counts the number of pixels and generates control signals SI and PIXCLK for the sensor array. The array is read permanently at a pixel frequency of 2 MHz.

The module is based on a 10-bit counter that is clocked at 16 MHz. Bits C_0–C_6 form the real pixel counter, while bits ph_0–ph_2 divide a pixel period into eight intervals. The latter three bits are also used by the EDGE_SM module when a light/dark edge is detected to monitor the transient oscillation of the output signal of the sensor array pixel by pixel.

EDGE_SM

The video signal arriving from the sensor array is converted into binary form by a comparator (LM311) and then applied to an edge detector which recognizes light-to-dark or dark-to-light transitions.

The phase information of signals ph_0-ph_2 determines when the binary signal is sampled within the pixel clock period. This enables the transient response of the video signal to be allowed for. The edge counter (e_0-e_2) is increased by one for each edge; the counter state is passed to EDGE_BUF.

EDGE_BUF

The EDGE_BUF module assumes the state of the pixel counter at each new edge. Up to four edge positions may be stored.

Measurement of the edge positions is started by the control computer with signal MODE. After the measurement has been completed, the edge positions from the computer are read bit by bit via the parallel interface. The single data bits are clocked by SCLK and output via s_{out}. Measurement and data transfer follow each other in not fewer than two read periods of the sensor array, that is, 128 µs.

COMPUTER PROGRAM

The software for reading the measurement values is produced under DOS in Turbo Pascal. It is accessed directly at the relevant I/O register via the parallel port.

Although the logic design allows very rapid measurements to be carried out, in practice the speed of measurement is determined by the (relatively low) speed of port access during the data transmission.

Tests with a Pentium 166 produced measurement times of 192 µs in the case of two edges, and 256 µs in the case of four edges.

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